

DOCUMENT RESUME

ED 256 901

CE 041 426

TITLE Robotics. Guidance for Further Education. FEU/PICKUP Project Report.

INSTITUTION Further Education Unit, London (England).

REPORT NO ISBN-0-946469-33-4

PUB DATE Apr 85

NOTE 51p.

PUB TYPE Guides - Classroom Use - Guides (For Teachers) (052)

EDRS PRICE MF01/PC03 Plus Postage.

DESCRIPTORS Automation; Behavioral Objectives; Course Content; *Curriculum Development; *Educational Needs; Electromechanical Technology; Employee Attitudes; *Employment Qualifications; Foreign Countries; Glossaries; Guidelines; Instructional Materials; Job Skills; Needs Assessment; Occupational Information; Postsecondary Education; *Program Content; *Robotics; Surveys; Technical Education; *Vocational Education

IDENTIFIERS Great Britain

ABSTRACT

This report contains materials to assist teachers and others in designing curricula in robotics. The first section includes the results of a survey of technicians and supervisors in nine companies involved with robots that was designed to gather information concerning the education and training needed to prepare for a career in robotics. The second section suggests broad guidelines for the design of courses dealing with robotics. Next, existing British curricula in robotics are reviewed. The fourth section consists of a brief discussion of the problem of identifying appropriate support for courses in robotics. Appendixes comprising approximately three-fourths of the booklet include instructional text on the robot as a device, robot stations, and robot applications; a list of curriculum objectives for robotics, a list of selected references, and a glossary. (MN)

* Reproductions supplied by EDRS are the best that can be made *
 * from the original document. *

ED256901

U.S. DEPARTMENT OF EDUCATION
NATIONAL INSTITUTE OF EDUCATION
EDUCATIONAL RESOURCES INFORMATION
CENTER (ERIC)

- ☒ This document has been reproduced as received from the person or organization originating it.
- ☐ Minor changes have been made to improve reproduction quality.

* Points of view or opinions stated in this document do not necessarily represent official NIE position or policy.

ROBOTICS

Guidance for Further Education

"PERMISSION TO REPRODUCE THIS
MATERIAL HAS BEEN GRANTED BY

J. Russell

TO THE EDUCATIONAL RESOURCES
INFORMATION CENTER (ERIC)."

PICKUP

PICKUP (Professional, Industrial and Commercial Updating) is an initiative by the Department of Education and Science to stimulate the updating role of education and the part colleges, polytechnics and universities can play in meeting the needs of business for post-experience education and training. Regional PICKUP agents provide liaison between academic institutions and employers.

PICKUP Regional Development Agents

Eastern Counties

Tony Winkless
PICKUP Office
Cambridge College of Arts and Technology
Collier Road,
Cambridge CB1 2AJ. Tel: 0223 352900

East Midlands

Ronald Arnfield
PICKUP Office
East Midlands Further Education Council
Robins Wood House
Robins Wood Road
Apsley
Nottingham NG3 3NH Tel: 0602 293291

London and Thames Valley

David Thomas
PICKUP Office
Oxford Polytechnic
Headington, Oxford OX3 0BP Tel: 0865 60264

North East and Cumbria

New Ellidge
PICKUP Office
Aliendale
Newcastle Polytechnic,
Coach Lane Campus
Coach Lane, Newcastle upon Tyne
Tel: 0632 663345

North West

David Esther
PICKUP Office
Woodlands Centre
Southport Road, Chorley
Lancashire PR7 1QR. Tel: 02572 75474

South East

Don Jarvis
PICKUP Office
Kingston Regional Management Centre
Kingston Polytechnic
Kingston Hill
Kingston upon Thames. Tel: 01-541 0209

South West

David Roskilly
PICKUP Office
Bristol Polytechnic
Coldharbour Lane
Frenchay
Bristol S16 1QY. Tel: 0272 659075

West Midlands

Paul Tranter
PICKUP Office
Wolverhampton Polytechnic,
Compton Park Site
Compton Road West
Wolverhampton WV5 9DX. Tel: 0902 24286

Yorkshire and Humberside

John Geale
PICKUP Office
Yorkshire & Humberside Association for
Further & Higher Education
Bowling Green Terrace
Leeds LS11 9SX. Tel: 0532 438634

Welsh PICKUP Development Agent

Ian Roffe
PICKUP Office
Polytechnic of Wales
Pontypridd
Mid Glamorgan CF37 1DL. Tel: 0443 493696

ISBN 0 946469 33 4
April 1985

© Further Education Unit 1985

Reproduction in whole or in part of the contents of
this publication is authorised for all non-commercial
educational purposes, provided the source is
acknowledged

All rights reserved with regard to commercial
reproduction of the contents

Printed by Lingholt Colour Ltd.

BEST COPY AVAILABLE



FURTHER EDUCATION UNIT

Elizabeth House York Road London SE1 7PH Telephone 01-934 9000

Chairman J G Owen CBE

Chief Officer Jack Mansell MEd CEng FIEE MIMech E

**Principals of FE Establishments
Secretaries of Regional FE Examining
Boards
Press and other interested Institutions/
Individuals**

Dear Sir/Madam

ROBOTICS - GUIDANCE FOR FURTHER EDUCATION

I enclose herewith a copy of a PICKUP report commissioned from TEC, now BTEC. The Report contributes to the guidance for staff concerned with the introduction of robotics into the technical curriculum and highlights the emerging demand for personnel who are multi-skilled.

Although spending in robotics is at present small compared with the overall spending on machine tools and other factory equipment, robots will play an increasingly important part in the production process, particularly as sensory systems develop to allow the robot to move easily and interface with the other parts of the production system. These advances together with increasing applications, will lead to the robot becoming an increasingly important aspect in vocational curricula if FE is to respond to new developments.

The report is based on a number of interviews with companies specialising in the field of robotics. Two important views emerged. Firstly, the robot consists of various systems (for example, hydraulic, pneumatic, mechanical, electrical, microelectronic), which traditionally have not been included in one engineering curriculum, this must change if colleges are to respond to meeting the needs of personnel working, or likely to work, with robots. Secondly, it was felt that the robot should be studied in the context of the production system, rather than as a peripheral device of a computer; thus, it is also necessary that production techniques and processes should be included in the engineering curriculum.

The needs of personnel returning to colleges for retraining in this branch of new technology should not be forgotten. They are likely to have been educated in a single discipline framework and provision must be made for widening their studies to include the topics mentioned above.

FEU work in the field of New Technology is expanding. Many of the problems identified in this document exist in other fields such as CNC. The entire area of manufacturing and design is being affected by the impact of the computer; this requires that new combinations of subjects are formed to enable the technician or craftsman to become multi-skilled and to respond to these new developments. A modest amount of support is available from FEU to assist in innovative and transferable curriculum development in this area.

In the meantime, additional copies of this document are available from our Publications Despatch Centre.

Yours faithfully

JACK MANSELL
Chief Officer

CONTENTS

	<u>Page</u>
INTRODUCTION	1
SECTION I. THE WORK-FORCE	2
Tasks	2
Previous Employment and Educational Background	2
Training and Education	3
SECTION II. CURRICULUM DESIGN	5
Previous Education and Experience	7
SECTION III. EXISTING CURRICULA	9
SECTION IV SUPPORT	11
SECTION V SUMMARY	12
APPENDIX A - Overview of Robotics	13
APPENDIX B - Curriculum Objectives for Robotics	35
APPENDIX C - References	42
APPENDIX D - Glossary	43

INTRODUCTION

1. This report contains material to assist teachers and others in designing curricula in robotics and includes a small survey of the work-force the results of which are described in Section I. From this, Section II suggests broad guidelines for the design of courses for personnel dealing with robotics. Section III briefly reviews existing courses on the basis of Section II and the report concludes with a brief summary.

2. A number of appendices support the report. Appendix A provides more information about the robot and its application. This analysis of the robot suggests that a knowledge of different systems is required, rather than a specialised knowledge of one. This is largely confirmed by the personnel interviewed. Thus the appendix, although not having 'text- book' depth of treatment, should assist in interpreting many of the results of Section I. Appendix B contains objectives covering skills and knowledge, to assist teachers and others in designing robotics curricula.

SECTION I: The Work-force

3. A semi-structured interviewing method was used to collect information about technicians and supervisors in nine companies involved with robots. Of the nine companies, seven were suppliers, one was a user (car manufacturer) and one both used and designed robots. One interviewer was employed who talked to on average three employees in each company. Considerable data was added at debriefing sessions with the interviewer.

4. Three categories of employee were requested for interview. These were a technician, a supervisor or senior technician, and a manager with responsibility for training and personnel. However, it was found that these categories were not widely used in the companies. Personnel described themselves in terms of functions, qualifications and experience rather than using categories such as technologist, or technician, as are used in the field of education and training.

TASKS

5. The main function performed by personnel was that of customising, i.e. modifying the production process to accommodate the robots, selecting or designing the appropriate attachments and software, installing and commissioning. Additional tasks were servicing, sales, manufacture and the assembly of robots. Only a few mentioned design. Some other activities mentioned were: training, publicity, testing, fault diagnosis. There appeared to be considerable interchange between tasks although this may in part be due to the robotics groups being relatively small, thus requiring personnel to perform a range of functions.

PREVIOUS EMPLOYMENT AND EDUCATIONAL BACKGROUND

6. Previous employment together with the education patterns (paras. 8-10) provide data which can be used in the development of training and educational courses. However, for previous employment, no clear patterns emerged from those interviewed. Some had previously worked in areas (e.g. welding) now affected by the application of robots. Field Service Engineering was another category of personnel who were qualified in electrical,

electronic or mechanical engineering and had some experience of Computer Numerically Controlled (CNC) machinery. They often had experience of servicing and fault diagnosis. It would appear that there was commitment to 'high technology' by some within the robotic company. Others explained that they developed from service engineers to customising engineers, which involved a broadening of skills in that other parts of the production system had to be taken into account.

7. Those interviewed, at the technician and supervisory level, were qualified mostly at the HNC/Degree level. The subjects mentioned were:

- i) electrical/electronic engineering;
- ii) mechanical and production engineering;
- iii) instrumentation and control.

Although opinions about courses experienced varied, there were general feelings about the relevance of courses and the role of practical work. For relevance, there was a general disappointment expressed about the degree to which their previous studies contributed to their understanding of their present activities. In this respect, practical work was particularly criticised. On the other hand, topics such as the logical approach to fault finding, logic devices, servo control and hydraulics were recalled as being of relevance.

Whilst it must be accepted that personnel working in new fields, such as robotics, are faced with a broader range of technology, the criticisms may point to the ways in which courses may be improved. Courses which have remained unaltered for many years may not meet the needs of students in robotics or in other fields affected by IT.

TRAINING AND EDUCATION

8. The most common form of training was 'on-the-job' with experienced engineers and technicians, along with familiarisation courses mounted by the company for purchasers of robots. The familiarisation courses appeared to be broadening and included electrical/electronic/mechanical engineering, servicing, maintaining and the programming of robots.

9. Educational needs as perceived by personnel should contribute significantly to the design of the curriculum. Here, respondents placed emphasis on broad based courses. Subjects mentioned were: electrical and electronic engineering (particularly microelectronics), mechanisms, fault diagnosis, programming, control engineering, digital techniques, with mathematics in a supporting role. It was suggested that the introduction of a subject such as 'applications engineering' would strengthen the industrial relevance of the course. This could comprise case studies with topics such as specification writing, customising, installation and servicing.

10. Likely future developments were seen as the possibility of vision with the associated software, followed by the development of sensors and voice control. Other areas mentioned were software to make the robot user-friendly, the use of plastics in the construction of robots and new applications.

SUMMARY

11. From the interviews, the technician work-force appears to require a broader range of subjects than that offered in their formal education and vocational training. This is due to the robot comprising different types of systems and interacting with manufacturing systems, with the result that the technicians need a broader knowledge base than provided by their on-or off-the-job experience. The comments about breadth also extended to communications and business studies.

SECTION II : Curriculum Design

12. From Section I, curriculum design for courses in robotics must take into account :

- i) the range of systems of which the robot is comprised;
- ii) the relationship between the robot and the manufacturing system.

Curriculum design must reflect the needs of the technician work-force (outlined in Section I) and include an analysis of the robot and its interface with the manufacturing system. This approach may be summarised as shown in Figure 1.

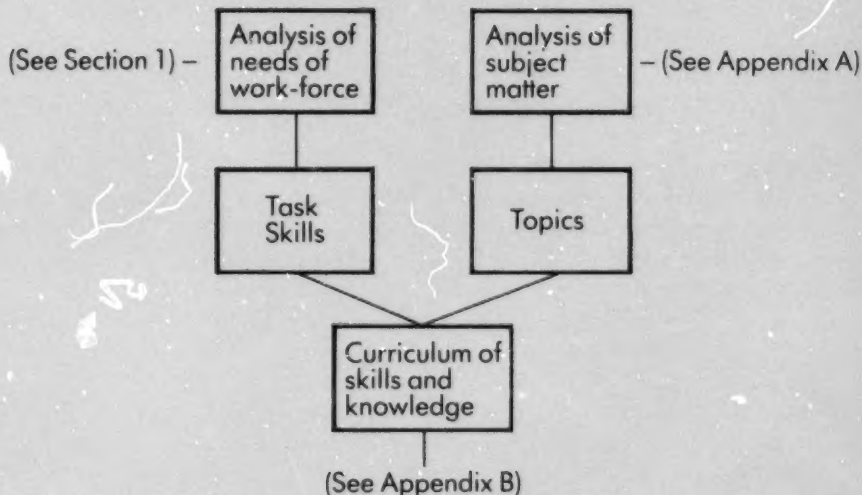


Figure 1 Curriculum Design Approach

13. Breadth of knowledge and skills were mentioned by the majority of those interviewed. This involved the relationship with other parts of the manufacturing system and the different systems within the robot. These aspects are expanded below and related to objectives in Appendix B. These are broad objectives which should lead to more specific objectives in order to define further the subject areas.

14. The integration of robot into the manufacturing process is brought about by control systems operating at various levels. They not only control the parts of the robot, but also relate the robot to the manufacturing system. For example, five levels of control may be conceptualised (Appendix A para 17) in describing the relationship between the robot and the remainder of the manufacturing system. Data is supplied from a centralised data base through workstations to the robot, resulting in the generation of trajectories in sequence with other parts of the manufacturing system. Objectives covering these levels of control are contained in Appendix E (topics C, D and E).

15. The robot itself consists of several systems as described by the respondents (Appendix A para 3): electronic; microelectronic; mechanical; electrical; hydraulic; pneumatic (see Appendix A). In addition, control systems and knowledge of programming were also mentioned. These systems relate to Figure 2 in Appendix A, where the drive could be electrical, hydraulic or pneumatic. The executive involves an understanding of microprocessors and programming (an example is given in Appendix B, topic A dealing with the executive) suggesting that material leading to an appreciation of microprocessors and an understanding of programming (the general principles rather than a specific language) should be included in a training background or course of study. The topic of robotic architecture is included and describes the behaviour of the robot as a device; Appendix A describes the various aspects such as manipulators (configurations: Figure 4), degrees of freedom, path control and sensors, which many respondents saw as the key to future developments in robots. This latter area is included in topic A of Appendix B. Objectives in this area and others are also listed in Robotic Arms: a Contribution to the Curriculum (FEU, 1984).

16. Mention has been made of designing a curriculum which places the robot in the context of the manufacturing system. In Appendix A in Work Place Layout (para 24) and Applications (para 25) some suggestions are made which relate the operation and selection of the robot to the overall manufacturing system. Other new technology areas could be included to equip students for coping with new developments in the manufacturing industry affected by IT. In addition, such courses may attract personnel who are

orientated towards new technology rather than the traditional areas of mechanical and production engineering. Topics such as Computer Aided Design, Computer-Aided Manufacture, and CNC could be included. (For example, see BTEC Guidelines.)

17. The previous paragraphs have dealt with the knowledge required by the work-force. However, respondents also mentioned activities such as specification writing, testing fault diagnosis, installation, and advising customers. Sections B, F, G, H, J, K, L and M of Appendix B are examples of objectives related to such activities.

PREVIOUS EDUCATION AND EXPERIENCE

18. The previous paragraphs suggest a content for robotics training together with suggestions for the broad design of courses. As mentioned earlier (para 7), the qualifications of the respondents tended to be of the conventional single discipline type, e.g. mechanical engineering. Thus students already qualified could take broadening, or bridging studies to give them a basis for understanding the new material. For example, a student with a qualification in mechanical engineering is likely to require introductory studies in topics such as electronics (digital and microelectronics), electrical engineering, control systems, and introductory programming, and provision should be made for this need. On the other hand, previous experience should be recognised, e.g. knowledge of production systems and mechanisms, and credit given where skills gained correspond to course objectives.

The survey shows that in designing courses, opportunities for learning and teaching high level skills should be created. This could take the form of a project or assignments which would give the learner an opportunity to carry out activities involving minor design work. Problems related to running a 'project', involving installation, commissioning and writing specifications, could also be included. The need for communication and interpersonal skills is evident, since respondents had been having to deal with customers and carry out functions such as training.

SUMMARY

19. Curriculum designers in colleges should place robots in the context of the manufacturing system whilst recognising that the robot comprises many systems. This means a broad core of knowledge in the areas mentioned (para 13) is required and the study of robots could take place within the computer-aided engineering area. Since many students have studied for qualifications orientated towards a single discipline, 'bridging studies' should be provided and where appropriate the skills of a mature student gained through work experience should be recognised and credit be given. Projects should be included to relate classroom activity to the skill levels required in working with robots.

SECTION III: Existing Curricula

20. In both advanced and non-advanced sectors FE opportunities exist for the introduction of robotics to technicians and senior craftsmen. They include BTEC Higher National Awards, and the CGLI pilot project 'Industrial Robot Technology'.

21. BTEC has issued guidance for Higher National Certificate programmes in Computer Aided Engineering* (CAE) which are designed for higher technicians. The pattern consists of bridging material (technology, science, mathematics, drawing, use of computers), a core including: design; microprocessors; computer-aided engineering; computer-aided design, with computer-aided manufacture as an optional unit. Further optional units include two units of robotics. BTEC has also developed a continuing education provision, providing recognition of further study or updating. Parts of the CAE package can be used, including robotics, within the framework for retraining purposes.

22. The City and Guilds of London Institute has published Industrial Robot Technology as part of the 220-Engineering Craft Supplementary Studies. This pilot project comprises: basic robotics; robot technology and control; pneumatic systems; hydraulic systems; and electrical and electronic systems. The subjects can be combined in various ways to provide courses** which are primarily aimed at engineering maintenance trainers, whose expertise helps in avoiding expensive time lost due to equipment failure. Although the emphasis is placed on the robot as a tool, reference is made to the relationships between the robot and the production system, Computer-Aided Design (CAD), Computer-Aided Manufacture (CAM), Flexible Manufacturing Systems (FMS) and artificial intelligence.

23. The structure of the courses described above appears to meet the needs of personnel, in that robotics are placed (in varying degrees) in the context of the overall production and design

*Computer-Aided Engineering: Guidelines and Units, BTEC

**Industrial Robot Technology: 220- Engineering Craft Supplementary Studies, CGLI

systems and are related to CAD/CAM. Previous specialised education is taken into account by the provision of bridging courses designed to broaden the knowledge base of the student. Thus the prerequisites for the courses are provided. The structure of these allows for the inclusion of projects, which should provide opportunities to make the courses more industrially orientated contributing to the idea of 'applications engineering' mentioned earlier (para 8). Microprocessors and programming can be introduced as necessary and recognised as important to robotics and CAM.

24. The courses described above are also used in career updating and retraining. Again the need to provide a broad base of knowledge, often at a low level, should be recognised. On the other hand, any previous experience related to the objectives of the course should be identified and given credit where possible.

CONCLUSIONS

25. Curriculum bodies are responding to the introduction of robotics and to new technology applications in general. However, colleges must respond quickly to the implications of new technology and the curriculum bodies must be equally ready to respond with validation and examination services to colleges so that national recognition of qualifications in the area of new technology can be assured.

Bridging studies have been frequently mentioned and the validation bodies have recognised the need for such opportunities. However, this does suggest that basic courses should be re-examined to ensure that they contain a core including both a broader range of technologies - based on relevant learning tasks - and complementary areas such as interpersonal skills and communications.

SECTION IV: Support

26. Colleges face the problem of identifying the appropriate support for courses in robotics. This includes providing information about robotics for teachers and considering equipment requirements. It appears that staff seek their information through books, papers and articles which are the usual channels where a new development is concerned. In addition, many of the robot sub-systems relate to staffing expertise already available. But because of the breadth of knowledge required, a team teaching arrangement encompassing the various disciplines involved may be required for introducing robotics into the curriculum.

27. For equipment, decisions are required as to whether to

- i) buy one or a few expensive robots or
- ii) buy more, smaller inexpensive robots made by educational equipment suppliers.

The small 'educational' robot demonstrates the relationship between the robot and the microprocessor, ie the robot acts essentially as a peripheral device to the microprocessor. This allows the student to program and gain some insight into the dynamic performance of a small robot. In addition, some colleges and manufacturers plan to combine robots with other devices to demonstrate the concept of a warm cell. Although there is some limitation in demonstrating the robot in the context of the overall production system, this can be overcome through the use of film, and visits to manufacturing units with robots. The subject of resources is developed in detail in Robotic Arms: a Contribution to the Curriculum (FEU, 1984), in which advice about specific robots suitable for colleges is given.

SECTION V: Summary

28. The report, in analysing the needs of the workforce and design of courses to meet these needs, highlights the need to introduce breadth of study into courses. Although the recently designed BTEC and CGLI courses mentioned above have this advantage, many existing courses in mechanical and production engineering do not. These courses are often single disciplines, contain no new technology and as a result leave the learner unprepared to deal with topics such as robotics. It is urgent that colleges and validation bodies review the content of such courses to ensure that the content is related to the needs of students in, or about to enter, areas of new technology such as robotics.

29. The report should contribute to the overall design of courses related to robotics by having done the following:

- i) outlined the tasks and views of the work-force;
- ii) suggested a design for courses in this area of work, with the following features:
 - a) bridging section constructed by analysing students' past educational and work experience. A content is specified to ensure that the student has a basis for studying robotics and related topics;
 - b) robotics for which material is provided in Appendix B;
 - c) related topics which may be of the new technology type, e.g. microelectronics, flexible manufacturing systems. Reference is made to material from BTEC.
- iii) explored briefly the issue of purchasing robots. Reference is made to an FEU publication containing specific guidance on this matter.

APPENDIX A - OVERVIEW OF ROBOTICS

Introduction	14
The Robot as a Device	14
Manipulators	17
Sensors	19
Locomotion	21
Executive	21
The Robot Station	26
Part orientation	28
Sequence control	28
Work place layout	29
Applications	30

INTRODUCTION

1. This appendix introduces the terms associated with robotics, providing a background to the basic ideas in the report. The robot is considered :

- i) as a device;
- ii) in the context of a workstation;
- iii) in relation to the production system.

THE ROBOT AS A DEVICE

2. The term 'robotics' describes the study of the robot, for which several definitions exist. The example below is that of the British Robot Association.

'The industrial robot is a reprogrammable device designed to both manipulate and transport parts, tools or specialised manufacturing implements through variable programmed motions for the performance of specified manufacturing tasks.'

This and other definitions emphasise programmability, manipulation and the ability to perform a variety of tasks giving rise to a considerable degree of autonomy. The presence of servo control is another aspect of machine autonomy which allows the robot to alter control through feedback. McIlvaine, Parsons and Kearsley (1981) indicate that some devices are termed robots although lacking servo control. This allows relatively simple pick and place devices to be classified as robots.

3. To illustrate the ideas in the definition, the robot is represented as a system shown in Figure 2. Various levels of control may be identified. First, there is the servo control using position, velocity, and acceleration feedback involving signals from sensors; secondly, there is the control due to the executive which contains the program; thirdly, the interface with the rest of the system allowing the robot to be integrated into the overall production system. The division between each of these levels of control may be blurred and will be discussed later.

In addition the manipulators and locomotion system receive power through the drive system, controlled by the feedback system, and contain a comparator element.

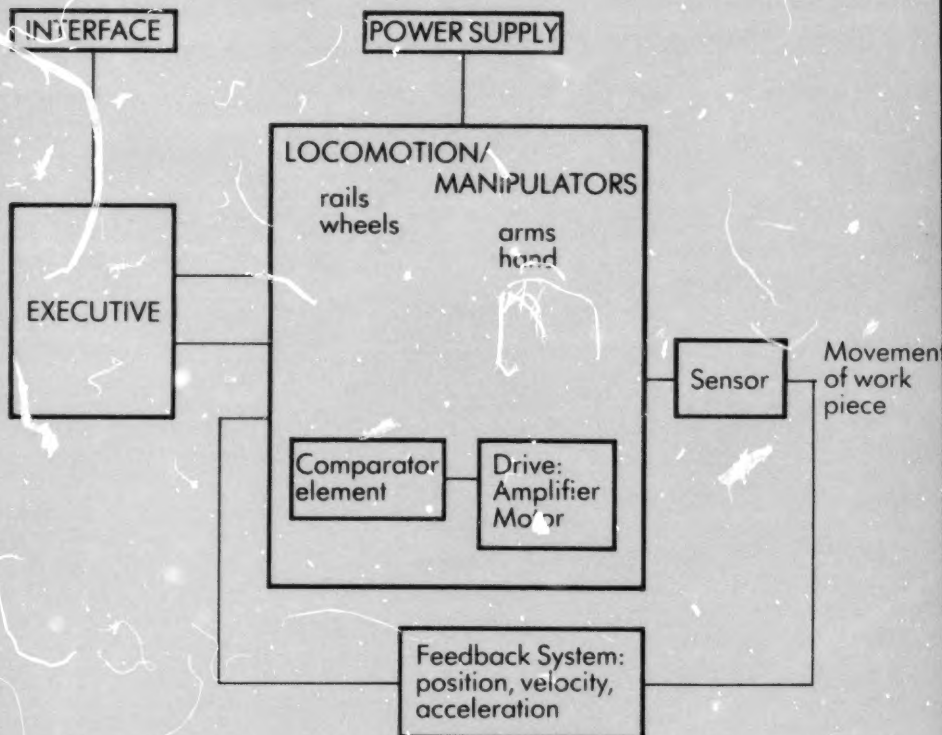


Figure 2: The Robot as Sub-systems

Thus the robot may be analysed in terms of the sub-systems:

- (i) manipulator;
- (ii) sensors;
- (iii) locomotion systems;
- (iv) executive.

This analysis is developed by McIlvaine, Parsons, Kearsley (1981), in which they suggest a hierarchical diagram showing robot capabilities (Figure 3). In addition they suggest a further level of analysis of each sub-system, the terms in boxes indicating areas where research and development work is proceeding. However, subsequent sections are based on the first level.

ROBOT CAPABILITIES

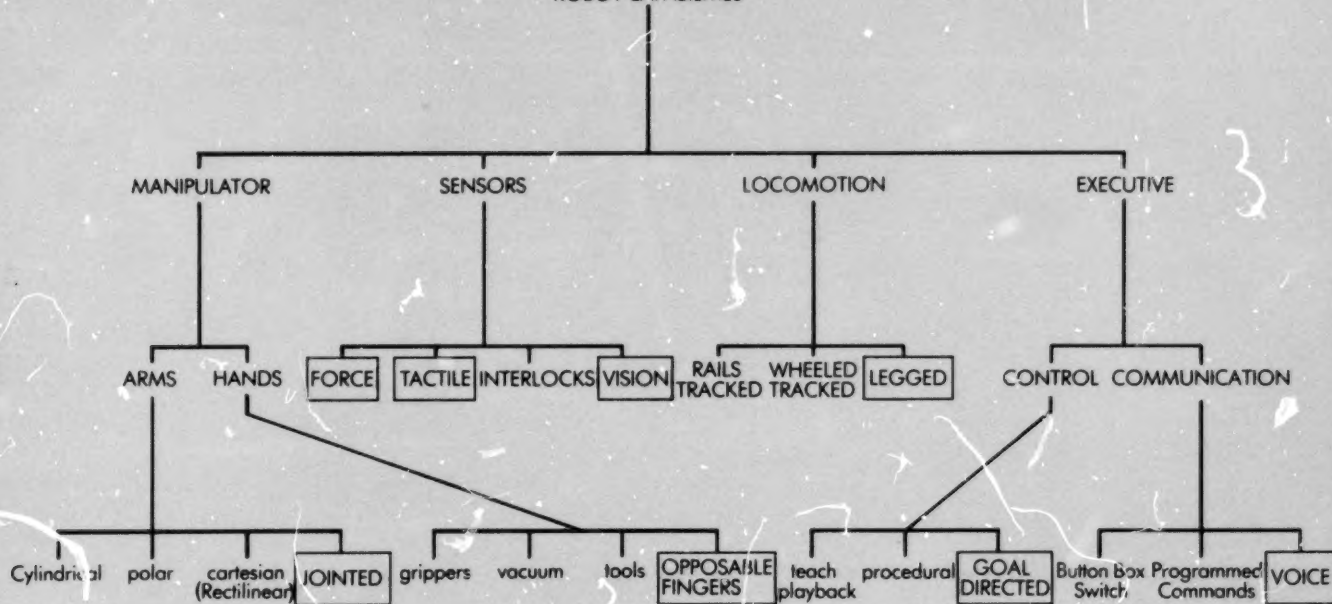


Figure 3: Hierarchical Analysis of Robot Capabilities

MANIPULATORS

4. The manipulator comprises the arms and hands which use the power under the direction of the control and sensory systems to move the tool or component to the desired position and orientation. The system is outlined by discussing robot configurations, the hands, power sources and path control.

5. The robot configuration depends on the movements at the arms which are the familiar limb/trunk-like components of the robot. Depending on how the limbs and trunk move relative to each other ie whether motion is translational or rotational, various overall configurations for the robot arise. Figure 4 (see reference 7 Appendix C) shows this for each class: cartesian, cylindrical, polar and revolute. Also shown are the working envelopes and movements (e.g. RTT indicates one rotational and two translational movements).

6. Each configuration has advantages and limitations and combinations of different configurations for the arm/wrist are found. For example, the cartesian and cylindrical constructions offer a large working area, high load capacity and easier load programming. Equipped with a revolute wrist, the robot can meet most application requirements. However, many new designs are based on the revolute system, enabling complex movements to be performed but requiring more complicated control systems.

7. The hand (gripper) is that part of the robot which connects the work piece or specialist tool to the robot. It is usually customised for specific applications and the cost of the gripper can represent up to 70% of the cost of the robot. The important aspect is the weight of the gripper since weight reduces the useful capacity of the robot.

A useful illustrated list of grippers, hands, pick ups and tools is provided by Engleberger and includes a mechanical gripper, hands such as cups, magnetic pick-ups and various tools

8. Degrees of Freedom describe the number of ways in which a robot may move (both translational and rotational). Thus to position a part in space requires six degrees of freedom; three

ROBOT CONFIGURATION

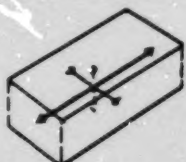
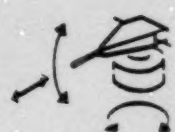
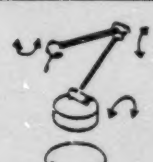
			MOVEMENTS.
CARTESIAN			TTT
CYLINDRICAL			R'TT
POLAR			RRT
ARTICULATED			RRR

Figure 4: Robot Configuration, Associated Volumes
and Movements

to move the part at the desired position and three to orientate it. However, approximately 70% of applications require only four degrees of freedom and the full versatility of the robot is not always required by the surrounding equipment.

9. The power for a robot may be pneumatic, hydraulic or electrical. Electrical units offer flexibility and hydraulic power is used for high capacity robots. Approximately 70% of robots work within a capacity of 0.5 to 25 kilograms.

10. Path control is either point-to-point movement or continuous path control. In the former the movement is controlled by specifying a series of points, whilst in continuous path control the movement of the arm is continuously monitored. Presently the majority of robots use point-to-point control.

11. An example of a control system may help to demonstrate the use of the ideas outlined in this section. Figure 5 (see reference 10 Appendix C) shows how teach co-ordinates from the pendant are transformed into rectangular co-ordinates which are in turn transformed into robot co-ordinates. These become the input to one of the servo systems which have velocity and position feedback.

The computer first operates in the teach mode and when switched to auto, the points stored are used to generate a path by computing points incrementally. Also stored are details of velocity, function and information about tools etc.

SENSORS

12. Sensors with the associated software are accepted by many as being the key area of research. Success in this will allow robot technology to advance considerably, for the robot, as part of a flexible automation system, will receive more accurate information about the state of the system and its own orientation, allowing the robot's performance to be modified.

Sight and touch are considered areas for advance. If this is so the next generation of robots with sight and touch, combined with a greater computing power, will be able to adjust more fully to a changing environment, decreasing the need (and cost) of

of requiring parts to be orientated for presentation to the robot. This may lead to a situation shortly where parts can be selected from a jumbled heap.

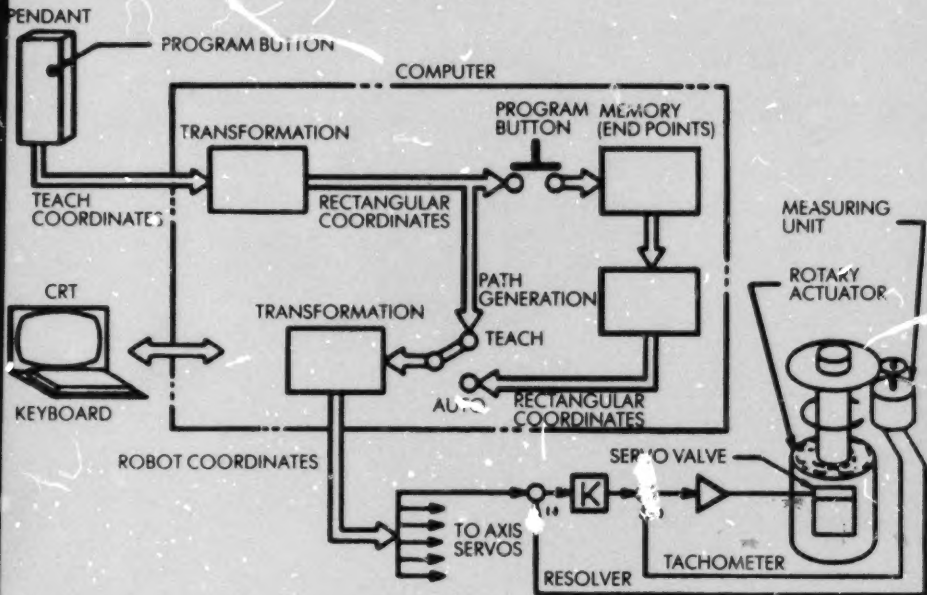


Figure 5: Control System Diagram

13. The actual devices used in sensing comprise a range of interlocking devices e.g. microswitches, photoelectric devices, infra-red detectors, pressure switches and vacuum switches. These provide information causing the start, continuation or halting of the movement of the robot. They are also involved in the safety aspects - e.g. if the safety gate is not closed the movement of the robot would be prevented through an interlocking device. Force sensors are used to detect torque slippage, and to provide information about the shape and orientation of the object.

14. Research is being carried out in fields such as vision, (including 3D, tactile and force sensors). Associated with these developments is the need for increasing computer power which will be provided by more powerful microcomputers (Allan, R. 1982).

In vision systems the trend is to develop systems with increasing levels of grey scales. Local features, in addition to global features, can be detected through the use of laser/ultrasonic soundings or through triangulation using light beams. Cross-checking of the object image with a master image held in the system's memory is also used.

A more radical approach to pattern recognition is the use of a network of Random Access Memories (RAMS) which behave analogously to a network of nerve cells in humans. Thus the network assumes certain states in response to an object. Distinguishing between objects thus becomes a question comparing the two corresponding network states. It is suggested that such devices would work at speeds comparative to the human brain process (Burnett, P. 1983).

LOCOMOTION

15. Locomotion describes the ways in which robots move into position and may involve mounting the robot on rails on overhead tracks since the device may be required to move with a conveyor or another workstation. Research on tracking robots and robots with various types of wheels is being carried out, some of which has arisen from space programmes.

THE EXECUTIVE

16. It is not only necessary to consider the control of a robot but most importantly, to relate the robot control system to that of the overall manufacturing system. The executive can be considered as part of an overall control system with levels of hierarchy, within which the control of the robot is placed.

17. This idea is illustrated by the five levels of control suggested by the National Bureau of Standards and described by Engleberger. A possible control system based on this idea is shown in Figure 6: for each stage, inputs, the function of the stage and the outputs are shown. The input to the highest level would be from a computerised data base holding information about product handling and the manufacturing context.

Control levels I and II are concerned with the workstation and III, IV and V with the robot, the final level being involved with feedback from actuators.

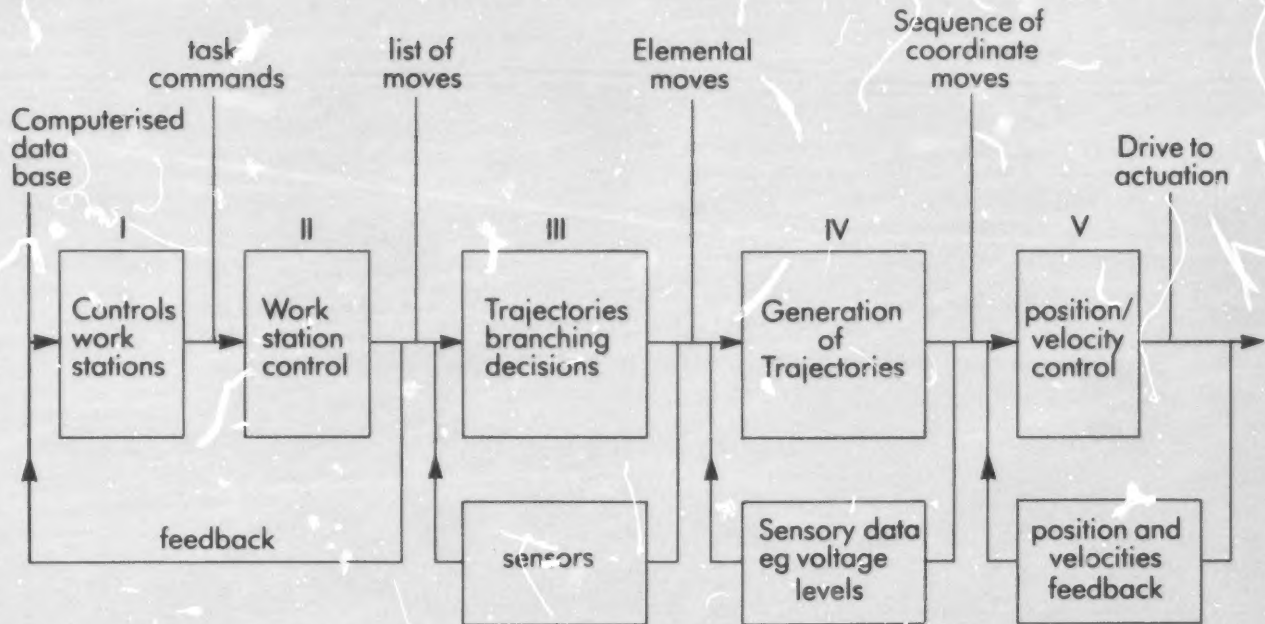


Figure 6: Control at the Various Stages

AN EXAMPLE OF CONTROL

18. An important aspect in the use of robots is the ease with which man may communicate instructions to them. This section will conclude with a brief example showing the role of the microprocessor and computer languages. In terms of Figure 6, levels III and V are being considered. It should be remembered that most robots are 'taught' by man.

19. The example is based on a description of a microprocessor, controlling a robot (Charles and Weston IERE 1982). The microprocessor controls a five axis robot with actuated pneumatic cylinders. Figure 7 gives an overview of the microprocessor controller, with the output and input modes connected through solenoids, and switches through interface circuitry. However, the main theme is the description of language structure for robots. This deals with the important area of communication between man and robot.

Two levels of software are discussed. The first involves direct reference to solenoids, microswitches, high/low voltage etc: that is, the language is orientated to the machine and thus takes the form of instruction codes in machine language. For example, 1007 causes solenoid seven (007) to be energised (1). More details are given in Figure 8 which shows the range of functions available and Figure 9 gives an example of a simple program.

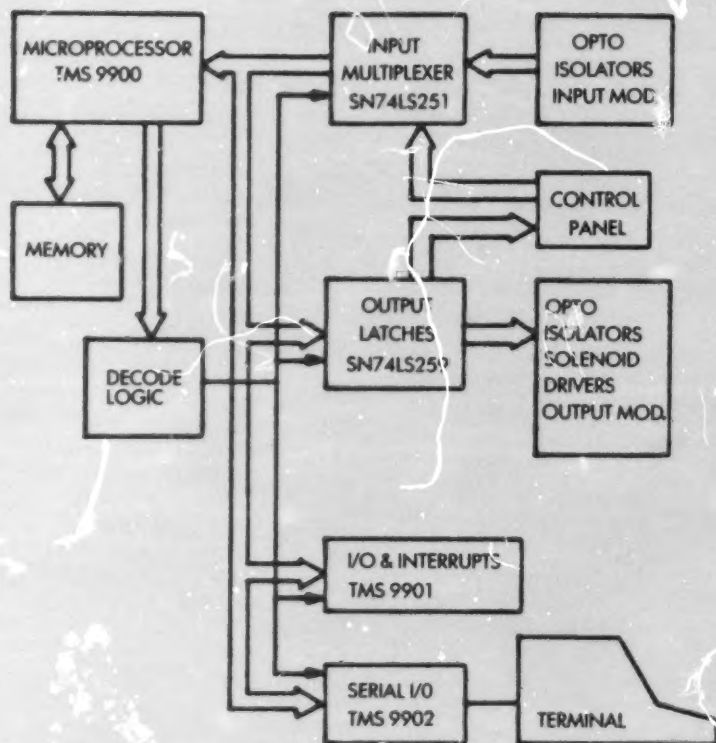


Figure 7: Overview of Microprocessor Controller

- 1 Energize a solenoid—format 1NNN (base 16)
where NNN = solenoid number (in the range 0 to 1023),
e.g. 1004 energizes solenoid four (Sol 4)
- 2 De-energize a solenoid—format 2NNN
where NNN = solenoid number.
- 3 Test micro-switch closed—format 3NNN
where NNN = micro-switch numbers,
e.g. 3000 test micro-switch zero (SWO)
and continues testing until switch closes
- 4 Test micro-switch open—format 6NNN
where NNN = micro-switch numbers
- 5 Time delay—format 4NNN
where NNN = time delay in hexadecimal and
relates to a base time of 0.1 s.
e.g. 43E0 causes a delay of $3EO_{16} \times 0.1 \text{ s} = 99.2 \text{ s}$.
- 6 Jump—format CNNN
where NNN = instruction number
e.g. C009 moves unconditionally to the 9th instruction
in the user program.
- 7 Stop—format 8000 stops the program
- 8 Jump on input high—format DNNN
MMMM
where NNN = input port number
MMMM = instruction number
- 9 Jump on input low—format ENNN
MMMM
where NNN = input port number
MMMM = instruction number

Figure 8: Instruction Codes

Instruction code hexadecimal	Instruction	Robot action
1005	output high 5—energize solenoid 5	Hand horizontal
402A	time delay $10 \times 100 \text{ ms}$	
2005	output low 5—de-energize sol. 5	
400A	time delay $10 \times 100 \text{ ms}$	Shoulder out full
1002	output high 2—energize solenoid 2	
3004	input low 4—switch 4 closed	
4006	time delay $6 \times 100 \text{ ms}$	
8000	stop	

Figure 9: Example Sequence Program

The second level aims at allowing the operator to communicate with the robot more easily by removing the need to refer to detailed parts of the robot such as the solenoids etc., or to refer to the code for the various functions. This reflects the general trend in computer languages, that they should become more 'user friendly'.

20. The need for user-friendly languages has given rise to interactive high level language sequences such as:

Q. WHICH AXIS (WAIST, TRUNK, SHOULDER, HAND, FINGERS)?

A. HAND

Q. VERTICAL OR HORIZONTAL?

A. HORIZONTAL etc.

EDIT and INSTRUCTION DECODE facilities are also available. The overall language structure is shown in Figure 10.

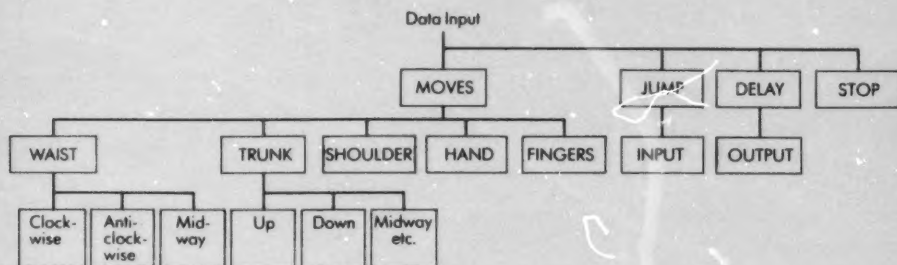


Figure 10: High Level Language Structure

The instruction may be entered through a console or customised programme panel shown in Figure 11 below.

THE ROBOT STATION

21. It is necessary that the robot works in harmony with the production system and the equipment involved in this is known as the robot station. Thus the station may be viewed as an interface, whose purpose is to relate the action of the robot to the production system and vice versa.

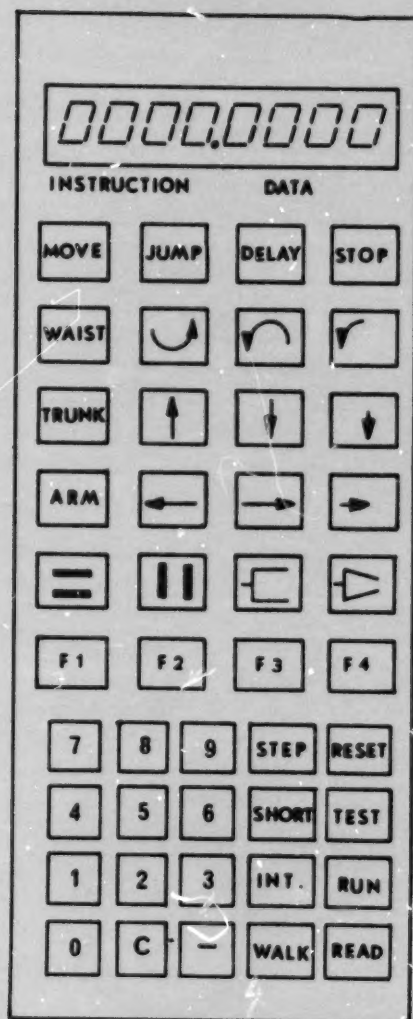


Figure 11: Customised Programmers Panel

The robot station will be discussed under the following headings:

- (i) Part orientation;
- (ii) Interlocks and sequence control;
- (iii) Work place layout.

Part Orientation

22. It is necessary that the part, presented to the robot, is in the correct attitude, enabling the robot to perform the appropriate action e.g. pick-up, welding, paint spraying. Thus each part of the batch must be presented to the robot in the correct attitude. There are various ways of achieving this such as palitisation, location of parts between guides. In addition the process of presenting the work to the robot is often redesigned since the robot brings different properties to the system in comparison with the human operator, e.g. quenching, where a hot piece of material is placed in water to reduce its temperature. When this process is carried out by a man the piece is placed in water, located and retrieved. However, when the process is performed by a robot, the robot maintains contact with the piece during quenching. This takes into account the difficulty for the robot in locating the work piece and recognises that the robot can handle very hot pieces of metal.

Part orientation depends on variables, such as the accuracy with which a part can be located on a conveyor system, or the speed of the conveyor.

In consequence knowledge is required of the system which presents and takes away parts to and from the robot.

Sequence Control

23. This refers to the control, based on signals from sensing devices which gives information to the robot about the readiness of the other parts of the system, or about malfunctions which

will affect the robot. In terms of the previously mentioned hierarchy of five levels of control, the sequence control could be considered at level II or III. The devices may be classified as:

- i) mechanically operated limit switches - these depend on the movement of a piece of machinery to trigger the switch and could indicate the extent of a movement;
- ii) microswitches acting as end-stops, e.g. by sensing the weight of parts on a palette; iii) photoelectric devices operated by detecting the interruption of a beam of light;
- iv) pressure switches using changes of pressure in airlines or hydraulic feeds;
- v) vacuum switches which check the vacuum of vacuum operated pick-up devices before allowing the robot to proceed;
- vi) infra-red detectors which are used for detecting the presence of hot work pieces and the temperature of parts;
- vii) electric signals which are passed to the robot from other devices, such as the computers acting as master controllers of the system.

Examples of sequence control are related to the robot interfacing through input or output convertors in the operation of safety doors, movement of palettes or tools, and sequencing operations with the surrounding machinery. It involves a knowledge of material handling necessary so that the appropriate layout can be arranged to reduce robot movements. The interface between the robot and the work piece involves selection of the appropriate gripping requirement, mentioned previously (App A. para 7).

Work Place Layout

24. This varies according to factors such as the way in which work is arranged around the robot, how work is brought to the robot and the way in which it travels to the work. Each method finds application depending on the features of the manufacturing system.

1) Arranging the work around the robot an example of this is where machines are loaded and unloaded by one robot, serving several machines which are within its sphere of influence. Work can be brought to the robot in several ways. The robot could be mounted on some form of rail or carriage system parallel to the line of the conveyor or it could be stationary while dealing with objects moving past on the conveyor system. The robot will be required to track the objects. The teaching operation may be performed on a stationary item where the points are taught in the normal way, but with a conveyor moving, the co-ordinates are modified in the light of the direction and speed of a conveyor system. That is, the control system changes the co-ordinates of the points taught when the item was stationary. This is shown in Figure 12 (See reference 10 Appendix C), where the teach and auto paths are shown. When the mode is altered from teach to auto the rectangular co-ordinates depend on the path generated and the signal from the measuring unit. The rectangular co-ordinates are transformed into robot co-ordinates which operate the robot servos. Associated with this form of working is the concept of a 'tracking window' which gives the range of the robot in relation to the moving line.

11) Robot travels to the work happens where machining cycles being serviced by the robot are particularly long. In the examples shown in Figure 13 (See reference 5 Appendix C), the eight machines are serviced by the one robot which could be mounted on an overhead rail as well as moving on the floor.

Applications

25. A brief review of robot applications is considered to suggest what makes it preferable to introduce robots into a process. Related to this are the financial implications of introducing robotics.

26. The following brief outline lists some applications in order of commercial development.

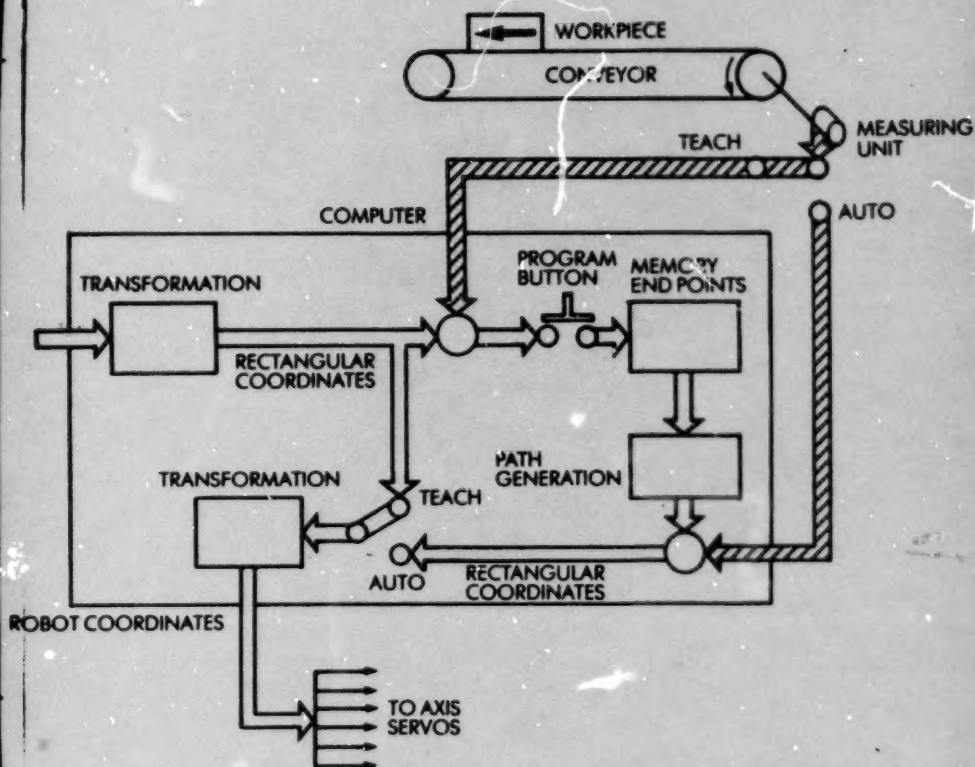
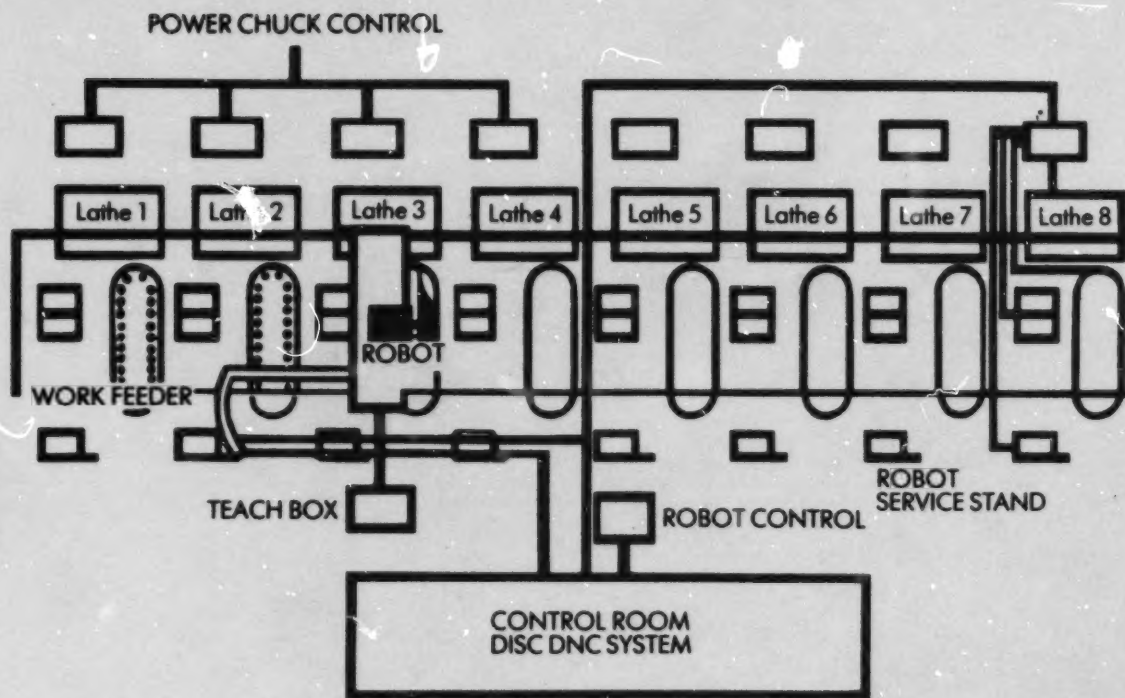


Figure 12: Tracking and Control System Diagram



38

Figure 13: Overhead Robot System

- i) Pick and place robots released workers from poor working conditions leading to high fatigue and monotony in departments such as forging shops which have an environment of heat and fumes. This application is also encountered in feeding noisy and dangerous machines.
- ii) Painting is a process which creates an anti-social environment for humans where special clothing and ventilation systems have to be provided. The robot can be applied in this area to great advantage thus removing people from such environments. If the flexibility of the robot is exploited, it may be reprogrammed to apply paint to different shapes.
- iii) Welding is a widely applied use of the robot. Both resistance and continuous path welding involve anti-social environments, associated with fatigue and monotony. When a robot is applied, the need for accuracy requires that continuous feedback is supplied i.e. the control system for correction of the weld position. In addition, with advances in the reprogrammability of robots, it is possible to introduce new products without incurring heavy retooling costs for welding.
- iv) Assembly is a process which has until recently remained man-orientated, particularly in batch manufacturing. This is largely due to the complex human skills involved in assembly, e.g. judgement, dexterity and flexibility. However, humans are subject to fatigue and distraction resulting from monotony and the robot with its increasing sensory potential and control is now overcoming the basic problems which prevented its use in this area.

27. In A Plant Search for Possible Robot Applications (1981) Ottinger suggests a general framework for identifying areas of activity which may be appropriate for robot application. The framework includes: evaluating tasks (e.g. accuracy required, weight of part), technical considerations (performance requirements, layout, equipment and/or process modification); economic considerations (labour materials, productivity, energy equipment, launching costs, cost avoidance, depreciation, and human factors

(operators, maintenance, unions, management, production). Thus a methodical approach to relating the possibility of the robot to production areas is proposed. In addition, the list suggests that a personnel department in order to perform such functions, requires a broad knowledge encompassing the plant and people working there.

28. Mention has been made of economic considerations. For a robot installation (or any other tool installation) an important question is how quickly the investment will be recovered. An answer is necessary for management. A simple pay-back formula is:

$$P = I/(L-E)$$

Where P is the pay back period (years)

I is total capital investment in robot and accessories

L is annual labour costs replaced by the robot

E is annual expense of maintaining the robot.

The formula can be modified to take into account the annual depreciation costs of associated equipment (Z) and production rate coefficient (U) that gives a measure of the production rate to that with the manual worker rate. The formula is:

$$P = I/(L-E + U (L+Z))$$

More advanced formulae can be derived to include the effects of wage inflation at the work place, and to assess capital and adaptation costs for industrial robots.

APPENDIX B - CURRICULUM OBJECTIVES FOR ROBOTICS

The following list of curriculum areas with general objectives should assist teachers and others in identifying the content of the robotics areas of a course. The objectives can be refined as necessary. For example, 'to identify service requirements' could generate more specific objectives relating to the electrical and mechanical services required by robots. The objectives are referred to in Section II: Curriculum Design, and relate to the skills required by the work-force and the topics related to robotics.

The list was compiled by members of the Robotics Group of Coventry (Lanchester) Polytechnic, and was partly based on the work of Greatrex (EITB).

Many specific objectives are given in Appendix B of Robotic Arms: a Contribution to the Curriculum (FEU, 1984), in areas such as architecture, power drives and actuators, grippers and manipulators, central systems, data acquisition and conversion, microcomputer control and interfacing, languages, arms, and robotics as a systems component.

CURRICULUM OBJECTIVES

A. Robot Architecture

(Related Topics: mechanical engineering, hydraulics, pneumatics, electrical engineering)

- (i) To understand robot classifications;
- (ii) to understand and select robots in terms of their geometric configuration and demanded working volume;
- (iii) to select and apply the appropriate drive systems;
- (iv) to analyse and quantify the dynamic performance requirements of the system;

- (v) to specify end-effectors (grippers) in terms of their gripping, sensory and manipulative capability;
- (vi) to select and stipulate motive modes.

B. Applications

(Related Topics: production engineering software)

- (i) to identify and evaluate fields of robot application;
- (ii) to undertake initial analysis of application areas;
- (iii) to execute extensive feasibility studies for robotic application, including the collection, evaluation and storage of existing systems data, the preparation of relevant graphical data, the identification of appropriate robot systems, the identification of appropriate computer/software capability, production of system specification and applications, taking into account flexibility, and the identification of operational problems and man/machine interface issues;
- (iv) to undertake supplier system evaluation.

C. Workstation and System Design

(Related Topics: mechanical and production engineering)

- (i) to obtain robot configuration specifications;
- (ii) to specify computer aided design systems for robot configuration and workstation simulation;
- (iii) to specify peripheral equipment requirements;
- (iv) to produce plant/workstation layout schemes;
- (v) to store and service CAD/CAM layouts;
- (vi) to specify service supply requirements;

- (vii) to evaluate system dynamics and generate concurrent program and asynchronous program strategies;
- (viii) to design outline robot operating programs;
- (ix) to interpret engineering designs and drawings;
- (x) to undertake engineering designs and drawings;
- (xi) to undertake definitions of program levels for flexible man/machine interfaces;
- (xii) to define safety and considerations;
- (xiii) to optimise system design.

D. Equipment and Devices

(Related Topics: microelectronics, digital electronics, mechanical engineering)

- (i) to understand types and applications of end effectors including mechanical grippers, magnetic pick-ups, vacuum systems, welding heads, cutting tools, attachment methods, materials, clamping forces, process tools, laser positioning attachments, and tool attachments;
- (ii) to understand computer system capabilities, peripherals, protocols, interfaces, networks and software;
- (iii) to understand types and application of peripheral equipment, transducers, interfaces and instrumentation;
- (iv) to understand the operational functions of process machines;
- (v) to understand methods of interconnecting equipment.

E. Microelectronics and Computing

(Related Topics: microelectronics)

- (i) to understand the hardware technology and systems applicable in robotics;

- (ii) to identify the function, role and operation of peripheral hardware;
- (iii) to understand the methods of interfacing hardware and systems;
- (iv) to understand software engineering methodology;
- (v) to understand the utilisation of software systems.

F. Maintenance

(Related Topics: computing/microelectronics, services)

- (i) to identify performance standards and tests;
- (ii) to interpret maintenance requirements for the total range of discipline areas involved;
- (iii) to establish robot maintenance requirements;
- (iv) to establish equipment and device requirements;
- (v) to establish workstation requirements;
- (vi) to define services supply requirements;
- (vii) to define computer system maintenance requirements;
- (viii) to maintain software standards and produce/update schedules;
- (ix) to define peripheral machine and equipment requirements;
- (x) to undertake fault diagnosis:
 - a) mechanical failure
 - b) controller failure
 - c) computer failure
 - d) computer peripheral failure
 - e) software failure
 - f) service supply faults

- g) identify faults in process and production machinery, peripheral equipment, transducers, instruments
 - h) system failure
 - i) interconnection faults
- (xi) to generate fault diagnosis procedures;
 - (xii) to determine operating performance standards;
 - (xiii) to initiate expert-system fault diagnosis;
 - (xiv) to establish operational wear monitoring;
 - (xv) to establish automatic data collection and annunciation systems;
 - (xvi) to prepare maintenance plans and schedules.

G. Installation

(Related Topics: services, engineering, contract management)

- (i) to undertake site inspections;
- (ii) to monitor site preparation;
- (iii) to monitor delivery of robot systems and peripheral equipment to site;
- (iv) to provide site management support relative to the types of contract;
- (v) to co-ordinate the provision of installation equipment;
- (vi) to monitor the assembly and installation of robot systems and, as necessary, peripheral and process plant.

H. Commissioning

(Related Topics: as for G)

- (i) to undertake robot, workstation and system trials;

64

- (ii) to evaluate computer system operation, software and peripherals;
- (iii) to evaluate system operation and performance;
- (iv) to undertake fault diagnosis;
- (v) to optimise systems operation and performance;
- (vi) to recommend and undertake systems modifications;
- (vii) to supervise and control training for computer, workstation, system operation and support;
- (viii) to co-ordinate workstation/system handover to users.

J. Safety

- (i) to assess environmental operating conditions;
- (ii) to identify risk factors;
- (iii) to interpret and apply health and safety regulations;
- (iv) to obtain relevant safety data from appropriate sources;
- (v) to define safety recommendations.

K. Engineering

- (i) to utilise knowledge and skills in:
 - a) construction engineering
 - b) production engineering
 - c) process engineering
 - d) plant engineering
 - e) control engineering
 - f) instrumentation and transducers
 - g) software methodology
 - h) programming
 - i) computer engineering

- j) maintenance and fault analysis
- k) computer aided design and manufacture (CAD and CAM)
- l) visual inspection techniques
- m) quality control.

M. Quality Control and Measurement

(Related Topics. Engineering measurements)

- (i) to initialise quality standard for material at entry;
- (ii) to establish measurement standards for in process gauging, sub-assembly inspection and final inspection;
- (iii) to define mechanical and electrical inspection equipment;
- (iv) to establish a calibration system;
- (v) to understand computer modelling techniques used for automatic inspection;
- (vi) to define environmental conditions for automatic inspection stations.
- (vii) to understand computer, computer peripheral, and software techniques for automatic measurement.
- (viii) to define in-process and post-process signature analysis procedures for quality gauging.
- (ix) to define on-line instrumentation requirements for process measurement and data capture.
- (x) to define software and data base requirements for quality control and measurement data and establish a feedback mechanism.
- (xi) to define local standards of compatibility with national and international standards of part and quality identification.

APPENDIX C - REFERENCES

1. BUSINESS & TECHNICIAN EDUCATION COUNCIL.
BTEC Higher National Awards in Computer Aided Engineering, 1982.
2. CITY AND GUILDS OF LONDON INSTITUTE. Industrial Robot Technology: 220 - Engineering Craft Supplementary Studies: 1983.
3. GREATREX, M.D. The Robotics Applications Engineer - An Evaluation of the Role. EITB (West Midlands), November 1981.
4. OTTINGER, L.V. Robot System's Success Based on Maintenance, June 1982.
5. ENGLEBERGER, J.E. Robotics in Practice : Management and Applications of Industrial Robots, Kogan Page (1980)
6. McILVAINE PARSONS, H. and KEARSLEY, G.P. Human Factors and Robotics: Current Status and Future Prospects, October 1981.
7. DENIS, F. Micro-electronics and Robotics : Keystone of Second Industrial Revolution 1982, Journal A (Belgium) V23 No. 3.
8. ALLAN, R. 'Industrial Electronics', April 1982 issue Electronic Design
9. BURNETT, P. 'Spectrum', The Times Sept. 5, 6 and 7, 1983.
10. HOHN, R.E. Computed Path Control For An Industrial Robot, 1982 International Symposium on Industrial Robots.
11. CHARLES G.P. and WESTON, R.H. Microprocessor Controls for Limited Function Robots, Jan 1982, Radio and Electronic Engineering vol 52.
12. OTTINGER, L. V. 'A Plant Search for Possible Robot Applications', Dec. 1981 issue Industrial Electronics.

APPENDIX D - GLOSSARY

1. DEGREES OF FREEDOM are the number of ways in which a robot may move, including both translational and rotational movements.
2. EXECUTIVE is a control system associated with the manufacturing system, and it relates to the control systems of the devices comprising the manufacturing system such as robots.
3. INDUSTRIAL ROBOT is a reprogrammable device designed both to manipulate and transport parts, tools or specialised manufacturing implements through variable programmed motions for the performance of specified manufacturing tasks (British Robotic Association's definition).
4. LOCOMOTION describes the way in which a robot moves its position.
5. MANIPULATORS harness the power under the direction of the control/ sensory systems to move a tool/component to a specific point and orientation. Manipulators comprise arms and hands.
6. PART ORIENTATION is the process of presenting part of the robot in the correct attitude and may involve techniques such as palitisation or the use of guides.
7. PATH CONTROL describes the way in which the path of a tool or component is monitored and controlled.
8. PAY-BACK PERIOD is the measure of how quickly investment in robots and accessories will be recovered. Calculation of pay-back period involves quantities such as capital investment, labour cost (replaced by robot), annual expense of maintaining robot, depreciation, production rate.
9. ROBOT STATION is the equipment that relates the action of the robot to that of the production system and vice versa.
10. SENSORS are the devices that provide information about the state of the robot (i.e. its orientation) and about that of the system interfacing with the robot.

FEU

Board of management

Chairman

J G Owen CBE, Chief Education Officer, Devon

Members

J C N Beattie, National Association of Teachers in Further and Higher Education

J Deboo OBE, Confederation of British Industry

J W Ballard, Association of Principals of Colleges

Association of Colleges of Further and Higher Education

R J Hartles, Association of Metropolitan Authorities

R Jackson, Trade Union Congress

J Morris, Association of County Councils

E Norris HMI, Department of Education and Science

L Rees, Welsh Joint Education Committee

Rev Canon George Tolley, Manpower Services Commission

C R Walker, Department of Education and Science

Observers

Dr F D Duffin, Department of Education, Northern Ireland

J Howgato, Scottish Education Department

K McWilliams, School Curriculum Development Committee

P C Webb HMI, Welsh Office Education Department

Secretary

Jack Mansell, Chief Officer, Further Education Unit

Objectives

The objects for which **The Further Education Unit (FEU)** is established are to promote, encourage and develop the efficient provision of further education in the United Kingdom and for that purpose:

- a) to review and evaluate the range of existing further education curricula and programmes and to identify overlap, duplication, deficiencies and inconsistencies therein;
- b) to determine priorities for action to improve the provision of further education and to make recommendations as to how such improvements can be effected;
- c) to carry out studies in further education and to support investigations of and experimentation in, and the development of further education curricula and to contribute to and assist in the evaluation of initiative in further education;
- d) to disseminate and publish information and to assist in the dissemination and publication of information about recommendations for and experiments and developments in further education.

BEST COPY AVAILABLE

A limited number of copies
remain available for sale.

For information, contact the
Department of Defense,
Executive Order 12065,
January 1977.